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EFFICIENCY OF SIMPLIFIED ALTERNATIVE MODELLING APPROACHES TO PREDICT THE SEISMIC RESPONSE OF PRECAST CONCRETE HYBRID SYSTEMS

Alessandro Palermo, Stefano Pampanin, Athol Carr
University of Canterbury
Private Bag 4800, 8020 Christchurch, New Zealand

SUMMARY

Two alternative simplified modelling approaches in representing the seismic behaviour of different jointed ductile precast/prestressed connections/systems is herein illustrated. Particular emphasis is given to the modelling of hybrid connections, developed in the PRESSS Program (PREcast Seismic Structural System) coordinated by the University of San Diego, for frame and wall systems. The efficiency and accuracy of the two alternative simplified approaches and analytical methods, one based on section analysis procedure and lumped plasticity models and the other one based on the use of multi-contact spring models, are herein critically discussed and compared through analytical validations of a beam-column subassembly and a wall specimen.

1. INTRODUCTION

Recent developments in the research of precast/prestressed concrete structures for seismic areas have resulted in the experimental validation of different innovative typologies of ductile connections for moment resisting frames, wall systems (Priestley et al., 1999). In particular, a wide range of alternative arrangements for pure precast jointed connections of precast structural members is now available and developments are going towards a continuing improvement of the technology of systems/connections (Pampanin et. al., 2004).
A particularly efficient and flexible solution was offered by the hybrid system (Stanton et. al., 1997), developed within the U.S.-PRESSS Program (PREcast Seismic Structural System), coordinated by the University of California, San Diego: unbonded post-tensioning tendons/bars with self-centring properties are adequately combined with longitudinal mild steel or supplemental damping/dissipation devices, which can provide an appreciable energy dissipation. Typical hybrid solutions are shown in Fig. 1a for a beam-column subassembly and a wall system, respectively. The inelastic demand is lumped at the critical section (beam-to-column, wall-to-foundation) through opening and closing of an existing gap at the interface. A sort of “controlled rocking” motion of the beam or wall panel occurs, while the relative ratio of post-tensioning and mild steel governs the hysteretic “flag-shape” behaviour; an idealised behaviour is illustrated in Fig. 1b.
Adding self-centring capacity, as well as providing adequate amount of energy dissipation capacity to the connection, the seismic performance of hybrid systems has been shown to be at least satisfactory as equivalent monolithic solutions in terms of maximum displacement/drift demand and a definitely better behaviour if the residual deformations are considered (Pampanin et al., 2002). In the following paragraphs particular attention will be given to critical issues related to the modelling of precast concrete hybrid connections, assuming that the same considerations can be extended to steel and LVL hybrid systems. In particular, attention will be given to simplified approaches, based on section analysis

procedure and lumped plasticity models and multi-contact spring models. The analytical validation of the two different approaches, referred to beam-column subassemblies tested at NIST (National Institute of Standard and Technology) (Cheok et al, 1994) and the University of Canterbury (Rahman and Restrepo, 2000), and critical discussion and investigations will be carried out exclusively at global level.

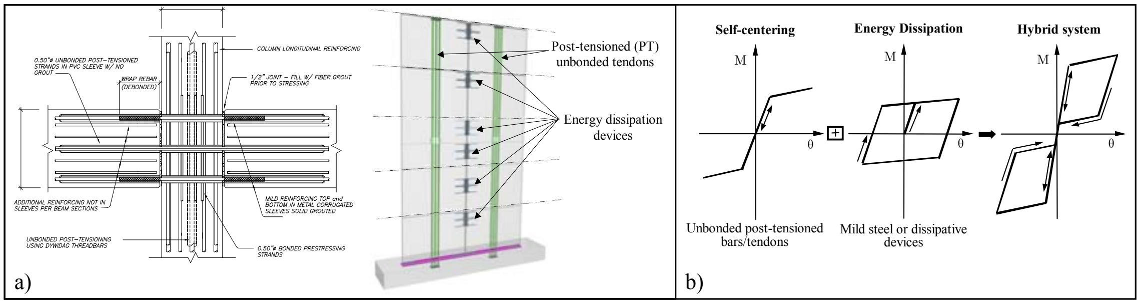

Fig. 1 Hybrid solutions for precast concrete frame and wall systems (PRESSS program, Priestley et al. 1999); b) idealised flag shape hysteresis loop (Pampanin and Nishiama, 2002).

2. SIMPLIFIED ALTERNATIVE MODELLING APPROACHES

The modelling of precast frame and wall connections/systems significantly depends on the bond conditions adopted for the longitudinal reinforcement, assumed as internal dissipation device passing through the critical section interface, and the partially/totally unbonded cable/tendon. An extensive overview on alternative analytical approaches, at different levels of complexity, to characterise the behaviour of precast/prestressed connections/systems, referring to the most general case of a connection where the “unbonded” concept is utilized, can be found in (Pampanin and Nishiyama, 2002). In the following paragraphs a brief description of two alternative simplified approaches is illustrated.

2.2. Multi spring model

The model is characterised by representing the contact in the critical section (beam-to-column, wall-to-foundation) with a multi-spring element; a similar approach has been previously started adopting two springs whose position was chosen estimating the position of the neutral axis of the section interface. Successively the model has been improved simulating the contact section interface with an increased number of springs, (Carr, 2004), (Spietz et al., 2004). The multi-spring contact element was set up for 2 to 10 contact points, representing the position of the springs; two different integration schemes, i.e. Gauss quadrature and Lobatto integration, were used to optimise the position of the springs and calculate their weighting.
The model achieves a good simulation of the local stresses, strains, variation of the neutral axis position at joint opening and as well as allows to consider the beam elongation effects. The characteristics of the springs can be properly chosen considering the different contact (monolateral, bilateral) behaviour of the section (concrete, steel ect.). The other elements characterising the hybrid connection, i.e. the unbonded post-tensioned cables and the external/internal energy dissipators with unbonded length, are modelled with longitudinal springs, pretensioned in the case of the unbonded PT cables. The hysteretic rule for the unbonded PT cable can be assumed non-linear elastic, if the cables do not reach the yielding point, while for the energy dissipators a proper hysteretic loop has to be chosen depending on the type of energy dissipator. Fig. 2a, 2b show the typical modelling of a typical beam-column subassembly and wall specimen. A representation in the case of straight cables is herein

represented but the modelling can be easily extended to parabolic drafted cables. The beam, column and wall are represented by elastic finite beam elements (crack and/or uncracked section properties).

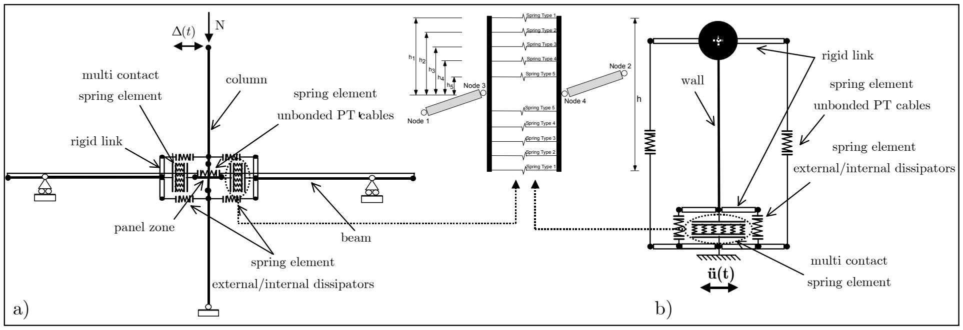

Fig. 2 Multi spring modelling: a) Schematic beam-column subassembly model; b) wall specimen model.

2.3. Lumped plasticity model

A lumped plasticity model can be efficiently adopted for hybrid connections where the main inelastic demand is accommodated within discrete critical sections (i.e. beam-column, column-foundation or wall-foundation interfaces). Due to the opening and closing of a single crack at the interface, an infinite curvature is developed at the critical section: therefore a moment-rotation relationship has to be preferred to a traditional moment-curvature when characterizing the section behaviour. Rotational inelastic springs in parallel, with appropriate hysteretic behaviour, can be assigned to represent the inelastic action at the beam-column (Fig. 3a) and wall-foundation interface (Fig. 3b) while elastic elements are used to represent the structural members as proposed in (Pampanin et al., 2001). One rotational spring is assigned a Non Linear Elastic rule to represent the self-centring contribution (axial load and/or unbonded cables), while for the second spring an hysteresis rule representing the energy dissipation contribution is adopted (Fig. 3c).

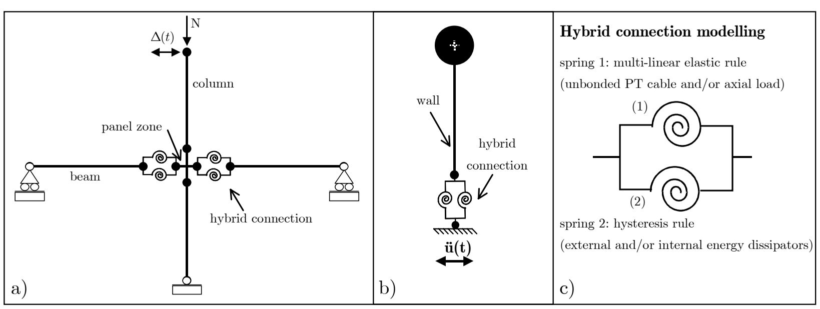

Fig. 3 Lumped plasticity modelling: a) Schematic beam-column subassembly model; b) wall specimen model; c) details of the connection.

The calibration of the two rotational springs can be obtained by evaluating the monotonic moment-rotation behaviour provided by each contribution, i.e. mild steel or energy dissipation devices, post-tensioned unbonded cable and axial load, referring to the Monolithic Beam Analogy procedure originally proposed by (Pampanin et al., 2001) and subsequently refined by (Palermo, 2004), which relies on a member compatibility condition in terms of displacements between a monolithic and a hybrid solution. As represented in Fig. 4, each curve contribution, obtained adopting the MBA (Monolithic Beam Analogy) can be linearized referring to the fundamental performance levels, i.e. the decompression point, loss of linearity point, yielding, serviceability and failure point. Fig. 4 summarises the above mentioned calibration procedure assuming for the cyclic behaviour of dissipator an Ramberg-Osgood hysteresis rule.

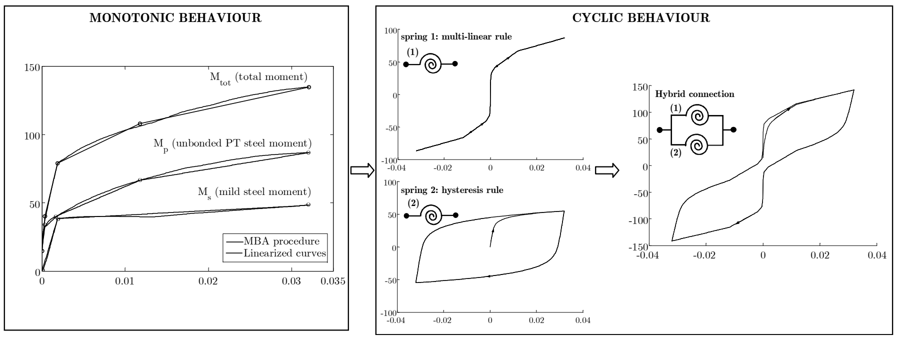

Fig. 4 Calibration of springs referring to the Monolithic Beam Analogy Procedure.

3. EXPERIMENTAL VALIDATION OF THE PROPOSED MODELS

3.1. Shear Wall Specimen

Three half scale precast wall specimens have been tested through quasi static push-pull analysis at the University of Canterbury (Rahman and Restrepo, 2000); all the units had the same dimensions; Unit 2 and 3 incorporated energy dissipation devices, simulating a typical hybrid precast connection. A validation of the experimental test of Unit 3 is herein proposed; the geometric data are shown in Fig. 5.

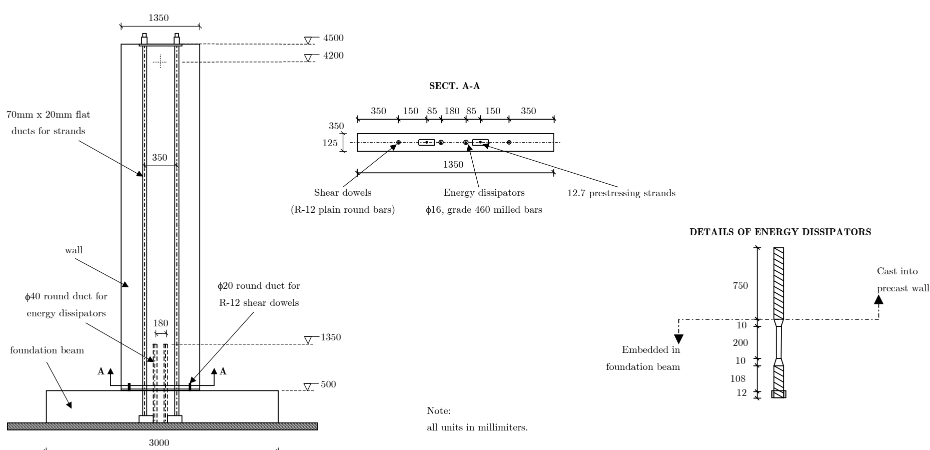

Fig. 5 Specimen and wall section reinforcement details

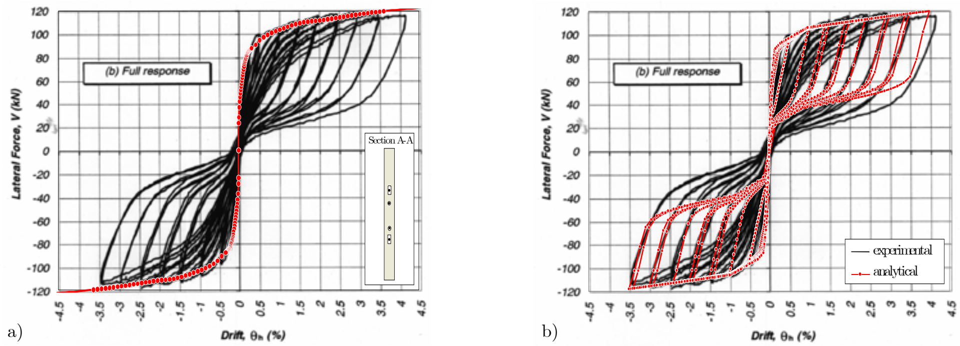

Fig. 6 Lumped plasticity modelling: a) monotonic experimental validation; b) cyclic experimental validation.

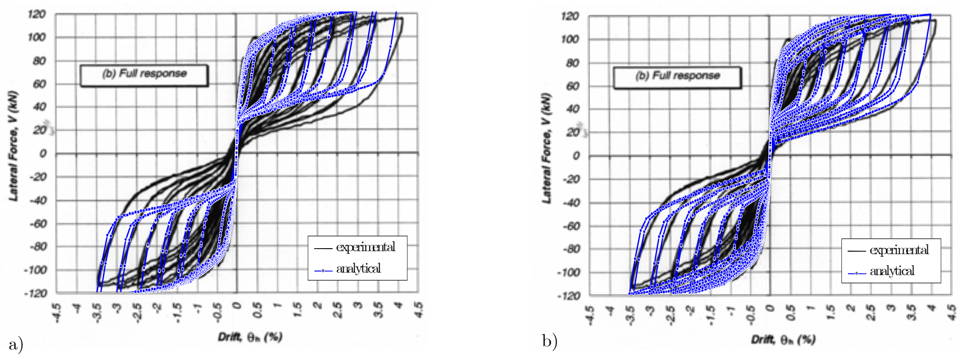

Fig. 7 Analytical-experimental validation with multi-spring modelling: a) Non Linear Elastic truss elements for PT cables; b) Elasto-plastic truss elements for PT cables.

3.1. Beam-Column Subassembly

An experimental program, divided into four phases, to examine the behaviour of 1/3 scale model precast concrete beam-column connections subjected to cyclic inelastic loads was initiated at the National Institute of Standard and Technology in 1987. Four different hybrid beam-column connections (1/3 scale) were tested at the National Institute of Standard and Technology (NIST) in the Phase Ivb (Cheok et al., 1994). For sake of brevity only the quasi-static test (imposed displacement history at the top of the column) on the O-P-Z4 specimen is herein considered as illustrated in Fig. 8.

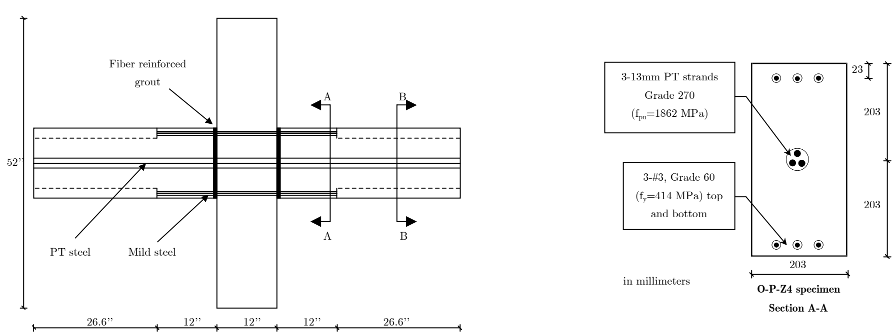

Fig. 8 Specimen and beam section reinforcement details (Cheok et al., 1994).

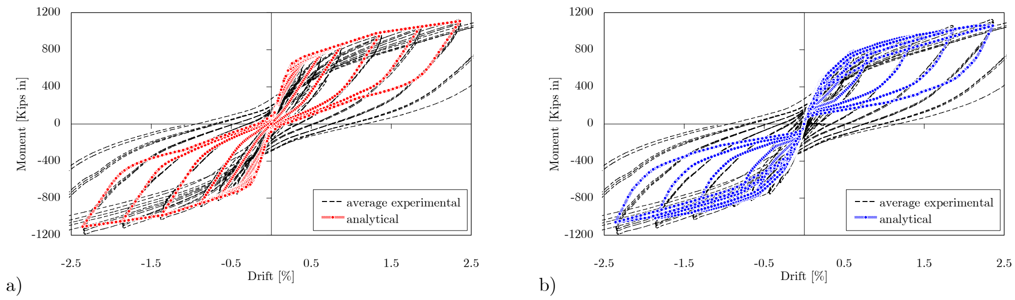

Fig. 9 Experimental validation: a) lumped plasticity modelling; b) multi spring modelling

4. CONCLUSIONS

A brief comparison of alternative simplified approaches and procedures to model the seismic behaviour of typical arrangements for hybrid connections of precast/prestressed concrete members in frame or wall system has been provided.

Simplified concentrated plasticity models as well as multi-spring models, alternative to refined fiber models, can thus be adopted as viable tools able to describe the seismic response of precast/prestressed systems, being the inelastic demand concentrated at the critical section.

Both the methods can correctly predict the moment-rotation capacity as confirmed by the validation of the quasi-static tests of the two specimens; the main advantage of the lumped plasticity model can be considered the low time of data preparation and the reduced computational cost especially when dynamic non-linear time history of multi-storey buildings are required. The limitation of this model, compared to the multi-spring model is emphasised in particular cases where the yielding of the cables occurs as happened for the wall-specimen; The advantage of the multi-spring model is to correctly predict the local behaviour, i.e. neutral axis position, stresses, strains as referred in (Spieth et. al. 2004) as well as the beam elongation effects, here not investigated. Further investigations are in progress for improving both the modelling which due to their simplicity, can be really proposed as a viable tools for the inelastic seismic response of structures with hybrid connections.

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